



Enhancing adaptive capacities in coastal communities through engaged communication research: Insights from a statewide study of shellfish co-management

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ABSTRACT

Intertidal ecosystems and the small-scale fisheries these ecosystems support are an important part of coastal economies, environments, and cultures. Globally, fisheries such as the soft-shell clam (*Mya arenaria*) face multiple stressors related to climate change, invasive species, and unsustainable land use. Co-management approaches based on shared responsibility for resource management among actors and institutions can build resilience to socio-environmental change by strengthening the use of science in decision making and promoting adaptive capacities such as learning and leadership. In this paper, we demonstrate how engaged communication research can help foster adaptive capacities to enhance the resilience of these systems. We describe perceptions of problems and successes in co-management, as awareness of problem constructions is essential for identifying the ways in which communication shapes adaptive responses. We demonstrate how specific communication factors influence adaptive capacities such as learning, leadership, and equity. We conclude with recommendations and demonstrated evidence of the value of bringing engaged communication research to bear on pressing issues of global coastal change.

1. Introduction

The health of small-scale fisheries is essential to the sustainability of coastal regions throughout the world (Berkes et al., 2001; National Research Council, 2010). Small-scale intertidal fisheries that depend on bivalves such as soft-shell clams, *Mya arenaria*, face numerous environmental threats (Food and Agriculture Organization, 2011), including warming ocean temperatures (Pershing et al., 2015), shifts in predation rates and/or species of predators (Beal et al. 2016; Sorte et al., 2010), increases in harmful algal blooms (Gobler et al., 2017), changing ocean chemistry, and persistent water pollution, among other factors (Harley et al., 2006; Hughes et al., 2003). These fisheries also face complex social issues, many of which are related to poverty and education access (Allison and Ellis, 2001; Defeo and Castilla, 2005; Sobhee, 2004). However, small-scale fishing communities are also rising to meet the challenge of these issues (Gutiérrez et al., 2011). There is an urgent need to identify social factors that enable such adaptation and the resilience of intertidal ecosystems and coastal communities.

The purpose of this paper is to demonstrate how engaged communication research can help meet this need in ways that also actively build adaptive capacities. The soft-shell clam fishery in Maine, a state in the northeastern United States (U.S.), provides an ideal case example for advancing this work. This context is ripe for engaged research and adaptive responses to socio-environmental change for at least three reasons, including the representativeness and diversity of issues within this fishery; the presence, scale, and organization of the shellfish co-management system; and the history of applied marine science in the state. First, this fishery is experiencing similar socio-environmental changes to those observed globally. Soft-shell clam populations are affected by a host of environmental factors, many of which are exacerbated by climate change, such as predation (Beal, 2006a, 2006b; Beal et al., 2018) and water pollution (Evans, Athearn, Chen, Bell, & Johnson, 2017). In eastern parts of the state, studies have detected decreases in clam recruitment over time (Congleton et al., 2006; Vassiliev et al., 2010), though recent studies found that high levels of recruitment are still occurring but rates of post-settlement mortality of juvenile clams exceed 99% (Beal et al., 2018). These ecological shifts

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impact the economic and cultural values of the clam fishery. Clamming has occurred on this coast for at least 1700 years (Dow and Wallace, 1961), as native Wabanaki tribes dug clams for food and trade (Hanna, 2000) and continue to do so today. Over the last two centuries, clamming was an important source of income within what were once diversified fishing livelihoods (Acheson, 1988; Brewer, 2012; Hanna, 2000; Stoll et al., 2016) and often occurred during the fall and winter months when other fishing opportunities were limited (Ambrose et al., 2016) and when water pollution concerns were lessened (Dow and Wallace, 1961). Economically, the soft-shell clam fishery alternates between the second or third most valuable fishery based on commercial landings and it also employs more than 1500 harvesters. Further, it accounts for more than 60% of the total soft-shell clam fishery in the U.S. (Evans et al., 2016; Hanna, 2000). In 2016, the landings value was \$16.2 million, down from \$22.5 million in 2015 (Maine Department of Marine Resources, 2018), and in 2017 the state experienced the lowest clam landings since 1925 (Johnson et al., 2014). In the last forty years state clam landings have decreased by nearly 75% (Beal et al., 2016), and eastern Maine landings have declined by about two-thirds since the early 1980's (Congleton et al., 2006). Though clam landings can serve as a proxy for clam population abundance, factors such as declines in the number of commercial clambers and changes in competing fisheries also influence landings volume, highlighting the need for reliable statewide stock assessments.

Second, the existing shellfish co-management system is one of the key sites where scientific and technical solutions, such as mitigating impacts from the invasive European green crab, *Carcinus maenas*, and other predators (McClenachan et al., 2015; Glude, 1955) by using methods designed to protect juvenile clams from predation (Beal et al., 2016 & 2018), are being advanced. Co-management is a governance arrangement that relies on shared responsibility and power among institutions (Berkes et al., 1991; Pinkerton, 1989; Plummer and Fitzgibbon, 2004) and this approach has a long history in Maine. The legal right of Maine people to harvest clams in the intertidal began with the 1641 Massachusetts Bay Colony Ordinance, which gave rights of fishing, fowling, and navigation in the intertidal to all residents (Hanna, 2000). Today, shellfish ordinances are administered by municipal shellfish committees with guidance from the Maine Department of Marine Resources (DMR) which has a legal mandate to approve ordinances. As determined by state statute (Title 12, Part 9, Chapter 623), towns with approved shellfish programs can restrict entry, charge license fees, require town residency for access, limit the quantity of harvest, set clamming seasons, open and close areas to harvest, and lease up to 25% of their intertidal area. The state requires licensing, defines acceptable harvest tools, sets a minimum harvest size and tolerance, and monitors public health (Hanna, 2000). Today, 74 out of Maine's 77 coastal towns co-manage their shellfish resources, representing 57 total shellfish programs, as some towns collaborate on regional and inter-local ordinances (DMR, personal communication, February 5, 2018).

In many fisheries, co-management has strengthened adaptive capacities and resilience (García-Ayllón, 2017; Gutiérrez et al., 2011; McClenachan et al., 2015; Pinkerton et al., 2014). We define resilience as the ability of a social-ecological system to anticipate and adjust to changes to stay within identified thresholds. For example, resilience is evident when clambers adjust to declines in clam populations by planting clams in an intertidal mudflat to maintain a functioning ecosystem and healthy economy. The ability to respond to change relies on adaptive capacities to maintain or transform system conditions when necessary (Chapin et al., 2009; Folke et al., 2010). Social and policy-based perspectives expand on this approach to resilience by calling attention to the resilience of what, to what, and for whom (Lebel et al., 2006). In the case of shellfish co-management in Maine, we focus on the resilience of intertidal ecosystems, clambers, and shellfishing communities to a set of interlinked ecological, economic, and social changes. The question of *for whom* calls attention to power, which is

particularly relevant in fisheries where power disparities contribute to social inequities (Béné, 2003). Further, experiences with and perceptions of state power shape relations within co-management and contribute to the complexity of communication in this context. Finally, paying attention to power is essential in engaged research that seeks to inform on-the-ground action but can also result in reinforcing existing power disparities (Silka et al., 2008).

Third, there is a history of applied research in Maine's fisheries due, in part, to the Land and Sea Grant mission at the University of Maine (UMaine); the proximity of university system campuses to the coast; frequent employment connections between UMaine's School of Marine Sciences and system campuses with marine biology programs and DMR; and the multiple fisheries organizations in the state. Important aspects of fisheries co-management in Maine have previously been documented, such as the role of cooperation and conflict in the lobster fishery (Acheson, 2013, 1988; Brewer, 2012; Waring and Acheson, 2018; Wilson et al., 2007); the influence of spatial heterogeneity in the harvesting and management of green sea urchins, *Strongylocentrotus droebachiensis* (Johnson et al., 2012; Cleaver, 2014); and how institutional characteristics influence adaptive capacities in shellfish co-management (MacLagan, 2014; McClenachan et al., 2015).

We build from previous studies of resilience in small-scale fisheries and in Maine's fisheries co-management system to demonstrate how engaged communication research can address complex problems for adaptation and resilience. We describe how co-defining problems and metrics of success in co-management can help identify workable communication strategies that can be used to strengthen information sharing and learning (Goldstein, 2012; Pahl-Wostl, 2009; Pinkerton, 2009), diverse forms of leadership (Gunderson et al., 2008; McGreavy et al., 2016; Stoll, 2017), and the development of shared identities and relationships (Agarwal and Buzzanell, 2015). After briefly reviewing concepts that connect theories of resilience and communication, we describe how engaged communication research, which is based on developing partnerships and co-defining research processes to strengthen linkages between knowledge and action, can promote adaptive capacities to enhance responsiveness to change within coastal fisheries (Cash et al., 2003; Trickett and Espino, 2004). We describe our engaged research methodology and qualitative methods for collecting and analyzing interview data (Creswell, 2014; Lindlof and Taylor, 2011). In our results, we share key insights about problem perceptions and criteria for success. We then detail how specific communication factors including strategic, relational, contextual and equity-related issues shape adaptive capacities in shellfish co-management. We highlight three communication recommendations that intend to enhance learning, collaboration, and equity and conclude by demonstrating how engaged research can enable linking social science recommendations with organizational change for resilience in shellfish co-management.

1.1. Communicating resilience within fisheries Co-management

Resilience is a useful framework for understanding complex interactions between ecosystems and people and has been widely used to explain dynamics within small-scale fisheries (e.g. Berkes et al., 2001; García-Ayllón, 2017). Specific factors in co-managed fisheries promote resilience (Basurto, Gelcich, & Ostrom, 2013), many of which connect with Ostrom's (1990, 2007) design principles and analytic framework for Social Ecological Systems (SES). For example, in a systematic analysis of 130 cases, the presence of community leaders and strong social connections, as well as appropriate enforcement, long-term management policies, and the participation of fishers in local markets predicted success in co-management (Gutiérrez et al., 2011). That study combined eight ecological, economic and social metrics including stock abundance, social well-being, and increases in unit price, among others into a holistic assessment of co-management success and SES resilience. Satumanatpan and Pollnac (2017) expand the analysis of social well-being in a small-scale fishery in Thailand, as they identify how social

factors, such as a sense of confidence in finding employment, positive orientation to the future, and an ability to cope with changes in a fishery were all positively correlated with feelings of individual well-being and environmental quality. Both of these studies highlight the value and multiple ways of conceptualizing resilience in the context of co-managed small-scale fisheries.

However, it is also important to recognize that co-management is not a panacea approach to resilience, as contextual factors will inevitably influence how management processes and outcomes occur in any locale (Plummer et al., 2012). In some cases, systems formally defined as co-management exhibit top-down power dynamics that limit the agency of non-governmental actors and enable corporations to engage in “stealth privatization” of shared resources (Wiber et al., 2010, p. 599). In other cases, the traditional governance mechanisms that preceded state-imposed approaches are more aligned with design principles, such as rules that match the local context (Gelcich et al., 2006). Given the promise and pitfalls of co-management there is an increasingly urgent need to identify factors that shape co-management in ways that simultaneously build adaptive capacities.

Co-management's commitment to shared responsibility points to the important role of communication, as upholding responsibility requires that people share information, learn from each other, and collaborate (Mulvaney and Druschke, 2017). Studies within SES paradigms that focus on communication often emphasize information sharing, learning, and dialogue (Cossarini et al., 2014; Murshed-e-Jahan et al., 2014; Rocha and Pinkerton, 2015). Brennan and Valcic (2012) describe the complexity of communication as a process of “navigating tangled webs of communication rather than bridging communication gaps” (p. 5). From their perspective, communication is how people bring their different perspectives together in ways that resemble weaving entangled webs, where communication is a dynamic process of making and negotiating meanings.

Communication studies as a field has much to contribute to such grounded, practical approaches to communication in co-management (Craig, 1989). With more than two-thousand years of praxis focused on human interaction and deliberation (Bizzell and Herzberg, 2001), rhetoric as a communication studies tradition offers helpful orientations to conceptualize communication within natural resource co-management contexts (Druschke and McGreavy, 2016). Fully elaborating the value of communication theory for resilience and co-management is beyond the scope of this paper. However, we highlight two primary values in how rhetoric offers: (1) multi-dimensional and practical approaches to communication and (2) critical orientations that shape engaged research commitments focused on power. Rhetoric is often defined as a practical art that focuses on the development of techniques that allow people to, in any situation, find the available means of persuasion (Craig, 1989; Aristotle, 2001). Contemporary approaches to rhetoric emphasize context and relationships (Bitzer, 1992) and approach persuasion as a process of identifying across difference (Burke, 1969). Approaching communication as identification requires paying attention to specific practices that shape how people connect across differences in perspective, identities, priorities, geographies, and more. These details may include the type and perceived urgency of a problem (Mulvaney and Druschke, 2017; priorities and interests of those involved; and the constraints on communication (Bitzer, 1992), such as language differences, technology, and spatial-temporal features. Focusing on the ways in which people perceive problems has implications for how resilience is ultimately defined and for issues that fall outside of dominant problem frames (Lebel et al., 2006). Further, focusing on priorities and needs within a communication situation provides a way to understand how everyday practices, like how chairs are set up in a meeting, the time of day at which meetings occur, or the extent to which people use one type of communication technology versus another, can come to matter in profound ways (Hariman, 1998; Senecah, 2004).

Taking this contextual approach one step further, scholars have recommended avoiding a one-size-fits-all definition of rhetoric to instead focus on strategic, relational, and ecological dimensions in any situation (Scott, 1973; Druschke and McGreavy, 2016). These dimensions can help guide the analysis of communication's complexity. For example, an extensive case analysis of communication within environmental decision making associated with the National Environmental Policy Act (NEPA) has shown how having access to information before a public hearing (strategic), the ways in which comments are received and incorporated into decision making (relational), the time of day and arrangement of a room (ecological) affect the perceived legitimacy and outcomes from a public participation process (Senecah, 2004). Here communication goes far beyond the ability to effectively convey ideas and consider different views to include a set of factors that influence the access to, legitimacy within, and influence over a decision making process (Klassen and Feldpausch-Parker, 2011; Smith and Norton, 2013).

Building on this multi-dimensional, practical approach to communication, the second value of a rhetorical perspective is the commitment to understanding and transforming power (McKerrow, 1989). Critical and engaged scholarship in environmental communication demonstrates this value in contexts closely related to shellfish co-management (Daniels and Walker, 2012) and for climate change adaptation (Endres et al., 2008; McGreavy and Hart, 2017). Environmental communication seeks to promote more equitable and sustainable ways of relating to each other and the ecosystems on which we depend (Cox, 2007). Asking critical questions about how language and power shape human interactions and reinforce systemic inequities is essential for identifying ways to transform systems (Endres, 2009; Sandler and Pezzullo, 2007).

Questions that focus on issues of power are also essential in engaged research contexts (Barge and Shockley-Zalabak, 2008; Israel et al., 1998; McGreavy and Hart, 2017; Trickett and Espino, 2004). Researchers who enter into engaged research settings must be sensitive to the resource and power disparities that exist between academic and partner institutions or communities. Van de Ven (2007) defines engaged scholarship as “a participative form of research for obtaining the different perspectives of key stakeholders ... in producing knowledge about complex problems” (Van de Ven, 2007, p. 265). Trickett and Espino (2004) expand on this definition when they describe engaged research as a process that recognizes:

the community as the unit of identity with resources on which to build. Collaboration is facilitated in all phases of the work, with mutual benefit for all partners involved. The process is intended to be empowering, attends to social inequalities, and is cyclical and iterative over time. (p. 15)

Here we see two distinct orientations that potentially differentiate engaged research as a form of knowledge production. First, engaged research assumes a commitment to egalitarianism, inclusion of diverse perspectives, and an orientation towards mutual empowerment and access. Second, engaged research aspires towards problem solving (Barge and Shockley-Zalabak, 2008; Trickett and Espino, 2004; Van de Ven, 2007). This orientation is consistent with commitments in sustainability science, which also guides our work (Kates et al., 2001; Miller, 2015). Sustainability science has identified useful strategies to guide how research partners become involved at specific stages, such as asking questions, developing methods, and assisting with analysis in iterative research design and implementation processes (Bieluch et al., 2017; Hart et al., 2015) which intend to help link science and other forms of knowledge to solve socio-environmental problems (Cash et al., 2003; Clark et al., 2016).

Thus, communicating resilience in small-scale fisheries co-management requires specificity and context-sensitivity to identify the resilience of what, to what, and for whom (Lebel et al., 2006). Bringing a communication perspective to resilience allows researchers to understand

complex patterns related to information sharing, access to and use of communication technologies, interpersonal and cross-institutional relationships, power dynamics, and the influence of local environments. As we describe in the following section, combining such a multi-dimensional focus on communication with an engaged research approach can allow for knowledge co-production processes that link social science and other forms of knowledge with decision making and begin to address systemic inequities in multiple ways (van Kerkhoff and Lebel, 2006).

2. Methodology

2.1. Engaged research design

Our methodology reflects a commitment to produce communication research that is useful and transformative for our research partners at DMR and the Maine Shellfish Advisory Council (ShAC), within the municipal co-management system, and in clamming communities. This commitment was also central to the Safe Beaches and Shellfish Project, of which our research was a part.¹ Our main research objectives sought to produce a communication-focused analysis of resilience within the municipal shellfish co-management system and provide recommendations to enhance resilience within Maine's shellfish co-management system. We conducted our engaged communication research in ways that allowed collaborators to co-define research questions and provide feedback on the development of methods and analysis, which was essential to advance research that was seen as useful and relevant (Cash et al., 2003; Barge and Shockley-Zalabak, 2008). For example, we provided updates and recommendations in ways that worked for our partners through multiple technical reports and presentations at ShAC meetings and Shellfish Focus Day at the Maine Fishermen's Forum. We also became actively involved in these forums, as the lead author was invited to join the ShAC and also became a member of the planning committee for Shellfish Focus Day.

In various ways, our research partners asked a similar question: How well is the shellfish co-management system working? We refined this evaluation-focused question into a set of research questions that would provide useful information for our partners and build new knowledge. Our overarching research question asked:

RQ 1: How does communication shape adaptive capacities in the context of shellfish co-management and responses to socio-environmental change (i.e. resilience)?

Following our conceptualization of communication, our related questions asked:

RQ 2: How do people perceive problems and how do these perceptions relate to definitions of success in shellfish co-management?

RQ 3: How do communication factors, such as needs for and access to information, relational capacities, contextual/ecological factors, and issues of equity shape adaptive capacities?

Building from the insights about problem frames, definitions of success and how strategic, relational, contextual, and equity factors shape co-management, we address a fourth question in our discussion and recommendations:

RQ 4: What communication approaches would strengthen adaptive capacities in soft-shell clam co-management?

2.2. Qualitative data collection and analysis

We used ethnographic and qualitative methods to collect data and analyze patterns related to communication and shellfish co-management (Creswell, 2014; Lindlof and Taylor, 2011). We initiated this research in September 2013 and concluded with a series of presentations and multiple technical reports to our partners in 2017. We conducted participant observations at two levels of analysis. To enable in-depth insights, we selected three municipal shellfish programs, including Bar Harbor, Gouldsboro, and the Frenchman Bay Regional Shellfish Committee (a regional program consisting of seven towns) and we took extensive field notes at a total of 30 municipal shellfish committee meetings from 2014 to 2015 (Fig. 1). These programs were diverse in terms of the number of licensed harvesters, composition of the shellfish committee, and the role of the shellfish warden. In 2016, we expanded to an additional 19 meetings of 11 shellfish committees across the coast (Table 1). This research design choice was based on a recommendation from DMR that a broader look at other programs within the fishery would improve their ability to link recommendations with decision making. We also reviewed 236 sets of shellfish committee meeting minutes from sixteen shellfish committees from April 2013 through June 2016 for communication factors such as meeting frequency, format, participation, and discussion content.

We used purposive, key informant, and snowball sampling techniques to interview shellfish stakeholders (Creswell, 2014; Lindlof and Taylor, 2011). We sought to interview people who had been involved in the shellfish industry for more than five years and represented a range of roles, including clambers, shellfish wardens, municipal officials, and agency and academic scientists. We used a semi-structured interview protocol with approximately thirty questions focused on perceptions of the status of clamming as a livelihood and shellfish co-management. We conducted 41 interviews with 39 participants associated with the co-management system (Creswell, 2014) (Fig. 2). On average, interviews lasted approximately 1 h and 35 min. We transcribed the interviews and the first, second, and fourth author coded transcripts to sentence level using NVivo11 Pro with multiple rounds of deductive and inductive identification of codes and themes and cross-checking for consistency in interpretations (Lindlof and Taylor, 2011). One question on the interview protocol asked participants to rate, on a scale of one to ten, how well the shellfish co-management system was working. To analyze the response to that question, we gave a numeric code and conducted descriptive statistics for measures of central tendency. The engaged research design supported our efforts to groundtruth, including direct feedback following presentations, and we also shared this draft with two key informants who confirmed and helped us refine our interpretations (Lindlof and Taylor, 2011).

3. Communication and adaptive capacities in shellfish co-management

In this section, we describe the ways in which communication shapes individual and community responses to socio-environmental change in Maine's shellfish co-management system. We begin with a focus on perceptions of problems and how these problems relate to definitions of success. We then detail specific communication factors such as access to information, relationships among stakeholders, how diverse forms of leadership enable adaptive responses, and equity-related issues in relative investments in science.

3.1. Perceptions of problems in shellfish co-management

Participants described a complex set of socio-environmental problems related to environmental quality, economic vitality, and community health and well-being. Our coding produced a typology that categorizes perceptions of these problems, including perceptions and concerns about climate and global change, predation, changes in clam

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Fig. 1. Locus map showing the location and relative size (2017 clam landings in live pounds, also listed in Table 1) of municipal shellfish co-management programs in the State of Maine where we conducted participant observations of shellfish committee meetings.

populations, water pollution and water quality concerns, unsustainable harvesting practices, user conflicts, declines in the number of clammers, barriers to coastal access, challenges with physical and mental health, and economic and political uncertainty (Table 2).

Views about climate change reflected national trends in the U.S., as the majority of participants acknowledged that the climate is changing and many noted the observable effects related to warming ocean temperature and changes in the height of the tides. However, perspectives about whether or not climate change is human-caused were more variable (Leiserowitz et al., 2017). Some were quick to describe how climate change is occurring and that it is anthropogenic, while others largely attributed the changes to unknown causes, natural cycles, and/or Mother Nature. For example, one shellfish warden characterized the changes in a way that accepted anthropogenic causes and at the same time acknowledged other attributions:

I'm concerned because there are a lot of people who believe in cycles, me being one of those people. But the problem is the cycles are different now than they were the past 50 years. In the past 10 years, [cycles] have been a lot different. They've been uncontrollable, uncontrollable cycles of stuff that you just have no – you're at the mercy of Mother Nature.

He went on to describe how the changes in observable patterns in the intertidal have a negative impact on clam productivity. One of the factors that likely shapes participants' general agreement that climate is

changing is the fact that their work in the intertidal brings them in direct contact with these changes. Many indicated that their direct experiences and observations over time served as the primary evidence for climate change. As one clammer who has been digging clams for more than 40 years acknowledged:

Yeah, there's change and I've noticed it. That's one where we're getting warmer. I'm a true believer of global warming. There's no doubt in my mind. I've seen it, experienced it. People sitting in an office don't see it. I live it, so I know.

Although some participants described relationships between climate change and human causes, the specific causes varied, ranging from fossil fuel consumption, capitalism, and population growth to more vague associations linking climate change with pollution, ocean plastics, and technology waste.

This research came on the heels of a noticeable population bloom in the European green crab, an increase that has been linked to warming ocean temperatures (Beal et al., 2016, 2018; Congleton et al., 2006; Glude, 1955). Clammers frequently described their encounters with green crabs out on the flat in very visceral ways, as seen here:

I was getting a lot of double tides during the summer nights when it was warm out, but you can sit there on an aluminum boat and hear this [Makes scrabbling sound] underneath the boat going like this and it's the crabs because you're moving the boat just a little bit and disturbing them. But even just sitting on a rock next to the seaweed you can hear them. [Makes drumming sound]. It's creepy.

The scale of the impact and overwhelming presence of these predators seems to motivate an interest in solutions, one of which is the use of predator netting and protective boxes that keep juvenile clams from being eaten (Beal et al., 2018).

Issues related to predation were sometimes, though not always, described as more important than water quality. Participants described in-depth knowledge about water quality, including relationships between land use, bacterial pollution, and water pollution closures. Some participants also noted a connection between climate change and water quality trends, though this perspective was not as widely shared as the more general view that water pollution is a problem. A state agency representative characterized the link between water quality changes and climate change in the following way:

The example I always use is all these huge rain storms that we now have in the summer time that are not necessarily normal. They used to happen, but not as frequently as they happen now. I think [they] are climate change related, and those kind of flood events have huge impact on clam harvesters. The Harrington guys, they kept track and last year they were closed 24 days last summer for flood closures because of rainfall events.

In addition to demonstrating the link between climate change and water quality, this quote also demonstrates one way that environmental change has economic impacts, as short-term water quality closures reduce income for clammers (Evans et al., 2016).

Economic issues were a primary concern and were emphasized much more frequently than other issues, especially those related to health and well-being. Participants described how multiple factors come together to increase economic uncertainty, including limited entry in town shellfish programs, the seasonality of supply and demand, and volatility of clam prices. Clammers are increasingly expressing concerns that clam prices are being affected by out-of-state imports. These market factors are compounded by an overall reduction in shellfish dealers, as more go out of business, and a consolidation in market power into the hands of fewer dealers.

The clam fishery is shaped by complex patterns of inequity between individuals within the shellfishery and across different types of fisheries and sectors. Issues of inequity, especially related to access to financial

Table 1

Shellfish program details based on annual reports and program website review, including the total number of commercial licenses, shellfish committee members, times the committee met during the calendar year, and details related to the warden role including full or part-time status and salary (FTE). ~ missing information.

Program	DMR Region	# Commercial licenses (2015)	Landings in live pounds (2017)	# Committee members	Meeting frequency	Warden details
In-depth analysis						
Frenchman Bay	2	78	322,617	7 committee, 7 regional board	approx.6/yr.	1 FTE
Gouldsboro	3	28 (limited)	39986	5 w/2 alternates	11/yr.	1 part-time
Bar Harbor	3	4 (limited)	5135	7	12/yr.	
Coast-wide analysis						
Scarborough	1	No 2015 info	210330	8 w/alternate	12/yr.	1 FTE
Yarmouth/North Yarmouth	1	6 (limited)	73348	6	12/yr.	1 FTE, 2 Part-time
Freeport	1	51 (limited)	379,496	7	12/yr.	1 FTE
Brunswick	1	62 (limited)	697,830	7	12/yr.	2 FTE
Harpwell	1	73 (limited)	105460	7 w/2 alternates	~	2 FTE, 1 part-time
West Bath	1	23 (limited)	91519	Number as determined by selectmen	~	1 part-time
Phippsburg	1	40 (limited)	109367	5 w/2 alternates	~	1 part-time
Waldoboro	1	176	910,903	9	6	1 full-time
St. Georges Regional Board	2	No info for 2015	486,490	~	~	~
Pembroke/Perry	3	164 (Pembroke only) (open)	230290	~	~	1 part-time
Machiasport	3	115 (open)	267,579	5	~	~

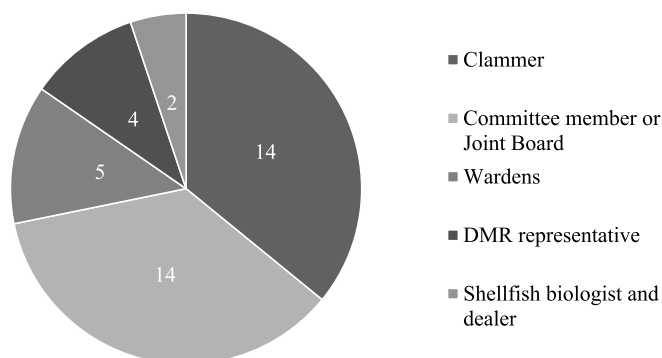


Fig. 2. Interview participants by sector. Participants were involved in the industry, on average, for approximately 27 years.

resources and persistent social biases, are particularly acute between clamming and lobstering. Lobster fishing eclipses all other fisheries with an annual landings value of more than \$500 million and this disparity manifests in complex ways, and we return to this in the discussion of resource allocation for research below. Clammers frequently describe how they face persistent social biases that are related to economic disparities between fisheries and in the context of coastal land ownership. One clammer describes the latter disparity when he says:

I mean money talks, you know? You go to these meetings and you got a lawyer sitting there, you got a guy with his lawyer sitting there and he spent \$5 million on his mansion on the shore. And they stand up at that meeting and they look out over that town and the residents of it and we're all a bunch of peons and nobodies.

Though all citizens can access the intertidal for fishing, fowling and navigation, coastal property owners are not required to allow access across their property, though traditionally most did. Restricted shoreline access for fishing is a consequence of wealth inequality and social bias, and interview participants described how it is now common for coastal landowners to disallow clammers from reaching the shore across their properties. Further, as coastal land becomes more valuable, clammers have been pushed out of their communities because they can no longer afford to live there. Since municipal licenses are required to clam in most towns, the loss of residency means a loss of livelihood for clammers and industry declines.

In addition to these social issues, participants described complex

and intersecting issues of human health and well-being, including conflicts, physical pain, and substance use disorders. There were multiple forms of conflict that showed geographic variation. In far down-east regions, participants described how persistent racism influences transboundary shellfish management between state and Passamaquoddy tribal government. As one resident of this region described,

Part of all this [conflict], of course, is the racial tension between natives and non-natives that's existed for ever since there's been a reservation, or ever since the Europeans came to [this] area, it's existed.

In terms of conflict between fisheries, in southern and midcoast areas of the state participants emphasized conflicts with wormers, where in more northern areas issues with the blue mussel fishery (*Mytilus edulis*) were more frequently heard. Clammers also experience pain and injury due to the physically demanding nature of their work, often with limited access to health care and insurance. As was frequently described and also observed in meetings, some clammers struggle with substance use disorders, including multiple forms of drug addiction and alcoholism, and have lower levels of education and access to information and internet technologies. These socio-economic issues intersect with each other and impact the overall resilience of the shellfishery (Béné, 2003; Sobhee, 2004). For example, clammers with substance use disorders or who are economically disadvantaged are often also the ones who suffer the most when water quality closures occur, as they do not necessarily have a savings or other sources of income on which to draw from during closure times. This may contribute to an increase in illegal activity and poaching. Fully applying critical race and feminist perspectives to analyze complex issues of power, race and other forms of social difference such as gender and class, inequity, pain, and substance use disorders is beyond the scope of this paper and remains as a gap in the literature on resilience and shellfish co-management that needs to be filled.

Participants generally agreed that metrics of success vary by context and that one-size-fits-all approaches would not work. We commonly observed intense deliberation about the relative importance of various problems and what should be done about them. However, there were also some clear patterns in how participants defined success. In economic terms, participants described the importance of increasing clam landings and, in most but not all cases, increasing the number of municipal commercial licenses. In terms of ecosystem-related successes, participants described the value of sustaining the clam resource over time, creating an effective system for stock assessments, and linking

Table 2

A typology of perceptions about problems associated with Maine's shellfish co-management system.

Category	Sources	References	Description
Climate and global change	33	188	There are varying perceptions about the rate and causes of climate and global change. Some stakeholders perceive that climate change is occurring and that it is human caused while others attribute the changes to natural cycles or Mother Nature (see “Change in clam populations” below).
Ocean acidification	19	26	
Anthropogenic attribution	8	12	
Ecosystem and habitat changes	4	5	
Sea level rise	2	3	
Predation	37	254	Participants emphasized concerns about the invasive green crab, as seen here: “Unless there's a huge recruitment clams coming, which we haven't seen. Probably partly because of the green crab infestation, which has been amazing to me to see what the green crabs can do to a cove. It looks like it had been dug by worm diggers and its all divots made by green crabs.”
Green crabs	35	128	
Predator protection	11	34	
Milky ribbon worms	4	7	
Other (moonsnails, gulls, etc.)	1	1	
Changes in clam populations	37	229	To varying degrees, the above climatic, ecosystem, and species changes were seen as connected to changes in the clam populations. Ideas about cycles and of the influence of Mother Nature seems to shape perceptions of climate change, especially levels of concern and the extent to which people see climate change as human caused. In many though not all cases, clams were described as being in decline and digging is occurring in the higher intertidal more than in the past.
Cycles and Mother Nature	18	40	
High intertidal digging	19	40	
Location and distribution	14	25	
Hauls and digging effort	10	18	
Clam size	6	9	
Population abundance	5	7	
Water quality	37	185	Although issues related to predation were often seen as more important than water quality, participants described in-depth knowledge about water quality including relationships between landuse and bacterial pollution, which results in short and long term water quality closures. Efforts to address water quality pollution emerged as an adaptive response in some communities.
Landuse	5	7	
Chemicals	4	6	
Perspectives on management and testing	4	5	
Adaptive responses	3	3	
Red tide and algae blooms	2	3	
Animal sources	2	2	
Disease	2	2	
Sedimentation	2	2	
Unsustainable harvesting practices	27	52	Poaching, which includes digging without a state or municipal license and also “peck digging” which refers to digging on a recreational license and selling commercially, was an important issue. Some expressed concerns about overharvesting and the impacts of industrialization of fisheries, as seen here: “They'll be dredging them like they do in a lot of other states. They just dredge the clams and come in with a backhoe, so to speak, and suck them out.”
Poaching	14	20	
Overharvesting	8	9	
Industrialization and privatization	6	6	
Regulation and enforcement	1	1	
Underharvesting	1	1	
User conflicts	18	54	Conflicts among users, and especially between clambers and wormers in southern parts of the state, and the conflicts are due in part to clambers' perception that wormers' digging negatively impacts the clams. These perceptions also intersect with social bias and hierarchy between fisheries, as well as resentment that wormers are not regulated by municipal ordinances and can dig across the state. Here is an example quote that shows some of these intersections: “I think there's gonna be some change in how worming is managed in association with clamming, because there's a lot of conflict right now. Not up here, but in southern Maine between the wormers and the clambers ... I don't know if regional programs are gonna allow that to be.”
Wormer-clammer conflicts	12	29	
Mussel-clam conflicts	4	5	
Within clammer communities	3	4	
General user conflicts	1	2	
Environmentalists	1	1	
Declining number of clambers	31	146	There is an overall decline in the number of state licenses sold, and participants describe how the municipal ordinances may be contributing to this decline as towns may be increasingly limiting the number of licenses they sell on an annual basis. Some see limited entry as a problem for the longer term sustainability of the fishery and others see it as a positive for maintaining and increasing the resource.
Limited licensing	26	103	
Municipal license access	16	28	
Younger generations	8	8	
Limits to volunteerism	3	3	
Self-employment issues	2	2	
Coastal access	14	41	Losing access to coastal resources, due to changes in land ownership, demographics, the impact of disrespectful activities such as leaving litter on landowners' property was a key concern. The connection between problems is evident in this quote: “One of the biggest issues right now is user conflicts inside the intertidal zone. We've lost a lot of our access points. Our local clam diggers have lost a lot of their access points because of the excessive use, not necessarily from the shellfishing industry but from other users, and that becomes problematic in terms of historical access points and the heritage in general.”
Gentrification and ownership	4	4	
Littering and disrespect	2	2	
Relationships	1	1	
Physical and mental health	39	520	There are a host of complex social, physical, and mental health issues, and fully characterizing these goes beyond the scope of this paper. However, the list here aims to demonstrate the relationship between injuries, persistent social bias an inequality in the shellfishery, and high rates of substance use disorders as the former are known risk factors for the latter. The high rates of substance use disorders, and especially opiate addiction which, in part, is related to physical pain treatment, limits adaptive capacities in the shellfishery by reducing the number of volunteers for conservation work, increasing conflict within programs, and contributing to unsustainable harvesting practices, such as poaching.
Injuries and pain from clamming	21	63	
Bias and inequality	14	26	
Substance use disorders	36	377	
Drugs	32	123	
Alcohol	29	75	
Poverty	15	50	
Physical pain	15	34	
Issues of respect	9	25	
Health insurance	15	22	
Education	11	17	
Physical abuse	2	5	
Literacy	2	2	

(continued on next page)

Table 2 (continued)

Category	Sources	References	Description
Uncertainty	31	121	All of these problems coalesce into creating an industry, economy, and a network of coastal communities that are grappling with uncertainty in their livelihoods and in their sense of what will happen in the future. Political
Economic value	24	90	uncertainty in state and federal government and scientific uncertainty about rates and causes of coastal change
Futurity	4	4	increase the need for biophysical and social science to support management decision making.
Political	5	5	
Scientific	10	11	
Water monitoring	4	5	
Water quality closures	4	4	

stock assessment information with license sales. One shellfish committee member talked about success in a way that linked the status of the shellfish resource and the number of commercial licenses, defining success as the ability “to maintain adequate levels of shellfish to maintain the livelihoods of a full suite of harvesters.” Finally, participants also identified a range of social successes, including an interest in having municipal shellfish committees meet on a regular basis, increasing town participation, strengthening community and cultural value, supporting an effective warden, and spurring innovation.

In sum, Maine's shellfish co-management system is a context shaped by a range of problem perceptions. As we demonstrate in the following section, taking an engaged approach to communication research can help people work through the differences in perspective and advance tailored solutions. We offer an analytic framework to help guide interpretations about how people perceive and are responding to problems, instances where people are working to address problems, and ways to support and leverage these efforts further.

3.2. Communication and shellfish Co-Management

The value of co-management for creating a space for people to come together to identify what is happening within an ecosystem and advance plans to respond is evident in one participant's description of the value of monthly shellfish meetings as a space where:

“You can get a group of people that can sit down and share the knowledge, which, I'd like to see things done. But I also know that if I start squawking too much, that it'll probably fall on deaf ears.”

Committee meetings are valued as a place to share knowledge, deliberate, and ultimately advance plans. In this section, we work through a series of strategic, relational, contextual, and equity-related communication factors that shape adaptive capacities in the context of these meetings and within shellfish co-management. We then provide specific recommendations to address communication challenges and enhance adaptation.

3.2.1. Strategic factors: access to information

Strategic communication focuses on the *form* of communication (Scott, 1973), and in our case this means the technologies and practices that shape information sharing. There are at least two key forms of communication that shape information access in shellfish management, including meeting minutes and the ways in which information is shared at shellfish committee meetings. First, meeting minutes provide an important record of the discussion, including decisions that are made, evidence of progress towards goals, and an entry point for getting involved. Meeting minutes can also promote effective listening and process transparency, which are essential in public participation in natural resource management (Senecah, 2004). However, the current system for making and maintaining this public record needs to be improved, as only 16 municipal shellfish programs had minutes posted online (28%) and gaining access to meeting minutes not posted online was time consuming and expensive. In addition, the limited availability of

meeting minutes online, especially in towns where meeting minutes for other town bodies are readily available, becomes another way in which social bias and the relative value of shellfishing in a community is communicated.

In addition to record keeping, municipal shellfish committees also need information about the status of the shellfish resource as a whole, changes in state policy, results of applied research, and water quality information. DMR Bureau of Public Health staff, namely area biologists and water quality technicians, are an important source of information and their attendance at the shellfish committee meetings is valued by participants. Based on our analysis of meeting minutes, we identified the presence of at least one DMR staff person (e.g. area biologists, program supervisor, or water quality staff) at sixty-eight (29%) of the shellfish committee meetings for which we have records from 2013 to 2016. At these meetings, we observed DMR staff provide regulatory information and details about trends and management activities in other towns. Interview participants indicated that the delivery of scientific information by DMR could be improved and there is also a need to understand whether the frequency of DMR participation is sufficient for the towns.

3.2.2. Relational factors: civic partnerships and diverse leadership

Relational communication focuses on the ways in which people form identities, connect across differences in perspective, and form interpersonal relationships (Agarwal and Buzzanell, 2015; Burke, 1969; Scott, 1973). Partnerships between managers, scientists, and the clamming community are an important way to enhance learning and strengthen community identity (Pinkerton, 2009). Participants described, and we also observed, a range of partnerships and projects focused on finding and fixing pollution, conducting applied marine science, implementing clam protection methods, and working with schools to link shellfish monitoring efforts with science education outcomes. Field experiments in the town of Freeport provides one example of such a partnership (Beal et al., 2018). This project began as a collaboration between the Maine Clammers Association, University of Maine Machias, and the Downeast Institute to initiate large-scale applied research to investigate the cause of soft-shell clam declines in Casco Bay and enhance shellfish populations. The series of field trials (2012–2017) have made important discoveries about the length and duration of both clam and green crab spawning season; the productivity of mudflats, including levels of current clam and crab recruitment; and how rates of predation, especially by green crabs, diminishes clam survival. In another project focused on addressing persistent water quality problems in the Medomak River, clammers and shellfish committee members from the town of Waldoboro partnered with the Maine Department of Environmental Protection, the Medomak Valley Land Trust, DMR, Maine Sea Grant, and others to innovate around a range of pollution detection techniques. These efforts have helped fix sources of pollution, such as pet waste around an important boat landing, and reopen more than 300 acres of closed clam flats.

When we look more closely at towns that are advancing adaptive strategies such as these, we see two key factors that influence the

development of these projects. First, diverse participation across sectors, including municipal, state, civic, and education institutions, enables information sharing and the ability to draw on multiple forms of expertise and economic resources. Second, multiple forms of leadership enable towns to draw on diverse skill sets from people within the community and address problems from multiple angles. Partnerships and leadership occur in tandem and are mutually reinforcing, as partnerships help promote diverse forms of leadership and specific types of leaders can initiate and strengthen partnerships. As seen in related natural resource management contexts, diverse forms of leadership foster abilities to articulate a compelling vision; solve problems; connect across institutions; and communicate effectively, especially with local and state media (McGreavy et al., 2016; Norberg and Cumming, 2008). Shellfish co-management programs that exhibited diverse forms of leadership demonstrated a greater ability to try innovative management techniques and adapt to social-environmental change.

As leaders, shellfish wardens play a key role in co-management programs. Wardens can perform recordkeeping, recommend management activities to shellfish committees, conduct shellfish surveys, and harness windows of opportunity to try new techniques or approaches to shellfish management. In most towns, wardens are often the only paid staff person associated with the shellfish program. Some wardens are employed through local police departments and may have a restricted focus on law enforcement (enforcing laws against poaching). Through our analysis, we identified five focal areas where wardens can help improve adaptive capacities, including learning, institutional memory, networking among partners, volunteerism, and leadership (Table 3) (Chapin et al., 2009). Not all committees have a full-time paid warden and even in communities that do, other people within the municipality may assist with some or all of the activities listed. However, shellfish wardens play a critical role in the shellfish co-management system and our observations indicate that they could play an even greater role in promoting adaptation.

3.2.3. Contextual and ecological communication factors

Contextual and ecological approaches to communication have become increasingly common in rhetoric in the last three decades (e.g. Bitzer, 1992; Edbauer, 2005; McGreavy et al., 2018) and such approaches help identify unexpected influences in natural resource co-management. There are myriad ecological influences and here we highlight two that were particularly influential, namely the tides and mudflats. First, the tides actively shape shellfish co-management activities. It is more difficult for clammers to attend shellfish co-management meetings when they were scheduled at low tide as this is when they need to be out on the flats. Some towns adjust their meeting schedules when they fall on low tide and this seems to improve participation rates. As one clammer described,

My shellfish committee is very active in setting the dates and picking the dates ... We always do Mother's Day [for conservation work]. For some reason, it has always hit that those are the tides for doing a lot of our activity.

In some cases scheduling meetings according to the tides, and especially conservation activity work such as seeding and netting mudflats, conflicted with other commitments such as holidays. Thus, setting shellfish management activities according to the tides helped resolve some scheduling tensions while reinforcing others.

The role of the intertidal mudflat itself served as a second primary ecological influence in shellfish co-management. The mud shapes shared identities in complex ways (Burke, 1969). For example, one can discern the clammers from non-clammers at monthly shellfish meetings by those who have traces of mud on their boots and clothing. The mud helps mark identity and creates and maintains social connections and differences in municipal meetings. Going out on the mudflat was also an important social activity, especially for non-clammers, DMR representatives, and researchers. Spending time on the mudflat helped to

create shared experiences and build relationships. Participants regularly told stories about the importance of time spent on the mudflat for establishing relationships and building credibility for science and management. In one case, a participant described how having the wrong boots made it nearly impossible to walk on the mudflat and the social impact this had: “[My supervisors] did not give me a hard time about it, but it was one of those you're never going to forget and that's what the clammers keep making fun of me about.” Paying attention to how contextual and ecological conditions shape natural resource co-management can provide insight into unexpected factors that shape adaptive capacities and can also point towards creative strategies for building relationships and improving participation.

3.2.4. Equity: power and resources within and across fisheries

We extend the discussion above about persistent social biases here to look at how power operates in shellfish co-management, focusing in particular on how power becomes institutionalized in resource imbalances between DMR and the towns, and across fisheries management within DMR. The following quote helps demonstrate the ways in which power operates through regulatory procedure and becomes institutionalized:

Well, it's supposed to be co-management, right? On paper that's what we call it. It's the only fishery that's really co-managed in the state. But the state has the authority to rescind your shellfish program. So, it's not an equal partnership. Although it's a co-management situation, the state definitely has more power in the relationship than the towns do.

The question that follows is therefore: how is this differential power established and how could structural inequities be addressed? As many of our participants have been involved in shellfish co-management for decades, they were able to reflect on the changes in DMR as an organization and in the relationships between DMR and municipal shellfish management programs over time. There were also a range of views about DMR's role and capabilities in managing the resource and implementing the public health program. Though there was variation in the extent to which participants trusted the water quality data, there was consistent agreement that the water quality monitoring program had improved over the years in part due to an intensive external review and subsequent program changes in 2009 through 2011.

Several participants described the important role that DMR, especially the area biologists, play in municipal shellfish management. However, in contrast to the general sense that efforts to monitor water quality and protect public health had improved over the years, many felt that the resources within DMR to support shellfish management and science were not adequate and/or had deteriorated. One participant described the value of DMR's support and the inadequacy of the resources in the following way:

Personally, I would like to be more interactive with the DMR and researchers about what the future is because we have a very good DMR: under-funded and under-manned but they're the best bureaucrats I've ever dealt with in my adult life.

As noted above, our analysis of meeting minutes showed that DMR representatives were present at 29% of shellfish meetings. It is important to contextualize this result in light of the large geographic area (3400 miles of coast and 74 towns) and the fact that four shellfish management staff, including three area biologists and a program supervisor, are responsible for assisting towns with their shellfish programs. These staff members are responsible for the soft-shell clam resource as well as quahogs, blue mussels, periwinkles, and marine worms. In some towns, DMR staff also do administrative work that is the town's responsibility. These tasks include reminding municipalities to submit their annual reports or addressing miscommunications that

Table 3

Shellfish wardens can support and enhance individual community-level adaptive capacities to sustain and manage the resource, respond to changes as they occur, and harness windows of opportunity to try new techniques or approaches to shellfish management and industry. This list is derived from resilience studies (Folke et al., 2010; Chapin et al., 2009; Norberg and Cumming, 2008) and from interviews and participant observations of wardens in a range of shellfish program activities.

Adaptive capacities	Recommended Communication and Program Activities
Organization, decision making, and group process	<ul style="list-style-type: none"> - Provide administrative assistance to the shellfish committee. The shellfish warden is an employee of the town and should be in service to clambers and committee members. - Prepare and bring maps to shellfish meetings to assist in management decisions. - Give regular “Warden Reports” at shellfish meetings. These reports typically include metrics such as numbers harvesters/ bushels checked, summonses, arrests, updates on program projects the warden oversees, such as water quality testing and resource monitoring.
Institutional memory	<ul style="list-style-type: none"> - Maintain records for the shellfish committee, including attendance records for meetings, minutes, noting motions/action items and reminding the committee of action items and motions. - As new people volunteer and/or purchase a license, help them understand program goals and objectives.
Learning, accessing, and using science and local knowledge	<ul style="list-style-type: none"> - Collect and share data that can be used by managers, such as information about where and how much clamming activity is occurring, shellfish harvesting trends, and environmental observations. - Coordinate with DMR to conduct routine and rain-event water testing and related monitoring activities. - Respect clammer knowledge.
Diverse forms of leadership	<ul style="list-style-type: none"> - Communicate and try to participate in other shellfish programs, especially in surrounding towns. - Serve as a liaison between the town and DMR. - Seek to encourage and support the formation of leadership from within the program, identifying and fostering license holders' and volunteers unique capacities and strengths.
Professionalism	<ul style="list-style-type: none"> - Prepare resource reports such as results of stock assessments, and annual reports for the town for review by the shellfish committee. - Participate in regional and state level meetings and share updates from these meetings back with the municipality.
Volunteerism and civic capacity	<ul style="list-style-type: none"> - Recruit and support participation from within the municipality, such as coordinating with town selectboard and municipal employees. - Plan and coordinate (including scheduling and notification, gathering supplies) conservation time activities.

arise. The administrative work limits the amount of time that DMR staff can spend on more direct shellfish management activities such as providing comprehensive monitoring and evaluation of the state's shellfish resource and advancing scientific studies.

The constraints on research are, in part, influenced by structural inequities in research prioritization and funding within DMR. Research planning documents from 2009 to 2011 highlight the disparity in the status of research between lobster and the soft-shell clam (Maine DMR, 2016). Where lobster showed research effort across multiple categories associated with commercial and recreational statistics, resource assessment, fishery independent surveys, gear research, and impacts of fishing on habitat quality, soft-shell clams only had research in two sub-categories, including commercial landings and catch by harvester, both of which are provided by shellfish dealers and not reflective of research investment. Although annual landings for lobster far exceed soft-shell clams, the total number of licenses is more directly comparable with approximately 4400 lobster licenses and 1500 state shellfish licenses in a given year. And, unlike every other major fishery in Maine, soft-shell clams lack a dedicated applied research fund (DMR, 2018), which is made even more striking by the fact that this fishery typically ranks as the second or third most valuable in the state. The disparity in research attention is a structural equity issue that shapes relative access to information in decision making and adaptive planning and potentially reinforces other social hierarchies between fisheries.

The differential research attention may be influenced by the organizational structure that locates shellfish management within DMR's Bureau of Public Health. This program oversees the state's application of the National Shellfish Sanitation Program (NSSP) to keep shellfish safe for human consumption. The mission of ensuring public health may take precedence over science and management activities to sustain commercial clam populations. Further, the DMR Bureau of Public Health is responsible for a diverse set of programs including marine biotoxin monitoring, water quality monitoring, shellfish dealer certification, shellfish growing area classification, shellfish management, and environmental permit review. As one shellfish warden commented,

[DMR] is doing all of these environmental impact studies too for all these different projects. And it's like, ‘Shouldn't that really be

somebody's full time job where that's all they do [so] these biologists are allowed to get out in the community, and communicate with the fishermen, and get down on an eye-to-eye level with them?

In contrast to the broad public health and management focus, the mission of DMR's Bureau of Marine Science which focuses on fisheries research and monitoring, conservation, management and education could be more conducive to supporting shellfish science and active management techniques that will be increasingly important due to climate change. We carry this point forward in the next section where we advance three recommendations that stem from what we learned about how people respond to problems, the ways in which visions of success have yet to be realized in this context, and the myriad opportunities for strengthening communication within co-management.

4. Communication recommendations

Maine is a microcosm for the kinds of challenges that global shell-fishing communities currently face. As we describe in detail above, these challenges include rising ocean temperatures, increased rates of predation, and shifts in water quality and chemistry. This situation is made even more challenging because abilities to effectively respond are constrained by conflicts, scientific and political uncertainty, economic and social inequities, and more. However, this case also clearly shows how co-management creates a social space in which people can come together across diverse backgrounds, learn from each other and adapt (McClenachan et al., 2015). As one of the interview participants expressed, our research helps show how “The communication aspect of shellfish management is critical to the success of it.” These efforts can be improved by specific communication strategies that strengthen adaptive capacities, including information sharing, relationship building, leadership, creativity, and equity.

4.1. Conduct yearly needs assessment to create more regular information sharing and an adaptive approach to co-management

Studies of adaptive governance show how information systems can enable feedback and tailored decision making about organizational

structure and priorities over time (Pahl-Wostl, 2009). There is a clear need to establish an information system among those who share responsibility for co-management and a yearly needs assessment would allow DMR to tailor its communication and science priorities to align with town needs. In addition to questions about how DMR could support co-management, an annual survey could identify existing capacities within a municipality that could strengthen co-management. Further, as one participant pointed out, there is a need to more effectively evaluate the conservation activities that a town undertakes, including measuring the results of the activity:

The [conservation] activity by itself is deemed a success because they did the activity. And there's no real measure of success that's based on well, how many clams survived or what would have happened if you had done nothing.

There are already mechanisms in place that could make this needs assessment more efficient than an annual stand-alone survey. For example, asking towns to answer survey questions as part of their annual reports would be one way of soliciting this information. DMR area biologists could also perform basic intercept surveys as part of their regular visits to town shellfish committees, where they use a portion of the meeting to get direct feedback. One of the possible problems with this approach may be response bias, as asking these questions in person could produce a desirability effect (Nederhof, 1985), meaning that responders may not feel comfortable expressing their true opinions directly to the area biologists. Triangulating these data with meeting minutes and personal observations could help address this potential bias. Finally, these types of questions could also be posed as part of an evaluation in other learning forums, such as the Fishermen's Forum, ShAC, or other shellfish-related meetings. DMR staff expressed consistent agreement that such a system would be valuable and are in the process of working with the authors to advance this recommendation.

4.2. Strengthen and expand an annual fisheries conference for learning, relationship building, and to promote equity across fisheries

The Maine Fishermen's Forum is an important annual event and represents one of the few opportunities for fishermen to get together, learn about current science, and improve their network across municipalities and regions (Brewer et al., 2016). Shellfish Focus Day occurs the day before the Forum officially starts, and in 2018 there were more than 100 participants including clammers, shellfish aquaculturalists, municipal officials, DMR officials, K-12 and graduate students, and a host of non-profit organizations. There is no other comparable learning event in the fishery, making this a crucial leverage point for connecting science with decision making. In the course of this research, we identified several challenges to effective science communication in this context, including the location, which restricts participation from fishermen who have to travel long distances and the need to include the practical and local knowledge of clammers. Recognizing the value of this event for improving strategic, relational, and equity-related communication factors, we have been focusing on linking this recommendation with action over the last three years in several ways. In terms of strengthening strategic communication and information access, we began filming this event and now provide an edited collection of videos. As we found, these videos have relatively high viewership compared to forum attendance (295 views for the 2018 videos, and 1179 total views since 2015) and there is opportunity to expand the reach by partnering with local cable outlets and providing links on town websites to increase access. There is also value in conducting an annual evaluation of this event to identify the topics that were of greatest interest to participants. This standardized evaluation is now helping guide the decision making about content to feature at the event. In the evaluation last year, participants indicated an interest in improving discussion and networking. This year, the authors joined an effort led by Tidal Bay Consulting and other partners to organize a social hour

and research needs assessment discussion session which has resulted in multiple technical reports to improve access to science and future research projects (Joyce et al., 2018).

We have also advanced multiple grant proposals to help create a learning network that would meet on a regular basis throughout the year and re-establish historic Clam Conferences that focused more directly on clam-related science. The need to create a separate event is connected to a persistent equity issue related to Shellfish Focus Day. There are benefits to having this day as a stand-alone event before the Fishermen's Forum start, including lack of distractions from competing presentations and exhibits as these other activities are not open yet, and value of having attendees in the same room for presentations and discussion. However, there are also disadvantages as participants do not have access to the same exhibit resources, food options, and they also have to give up even more work time than others if they also want to participate in the main days of the Forum. More importantly, the separation of what was previous called "Clam Day" is another structural inequity that reinforces exclusion and hierarchy. We are exploring ways to grow the boundaries of the Forum so that over time Shellfish Focus Day feels less like an add-on and more like an integral opening event.

4.3. Pursue organizational innovation and explore restructuring to grow capacities for shellfish science across institutions and scales

Where we have made measurable progress on the first two recommendations, this third and final recommendation is more exploratory, though we have begun to build capacity for improving shellfish science in municipalities and with DMR. In light of the discussion about resource distribution and equity, we recommend that leaders within DMR and in state legislature prioritize shellfish science and that if moving the shellfish management program out of the Bureau of Public Health into a science-focused program such as the Bureau of Marine Science would improve access to resources for shellfish science, then steps should be taken to reorganize so that this valuable fishery receives the scientific information that is required for adaptation in the context of rapid coastal change. The current status and use of the state's Shellfish Fund should also be examined (Beal and Coffin, 2018).

In addition to organizational restructuring, pursuing innovative ways to increase shellfish science and stock assessment, such as through partnerships with schools and citizen science initiatives and the development of an established research fund, could accomplish multiple objectives. Citizen science efforts can improve access to data for enhanced decision making. These types of programs have also been shown to help build adaptive capacities for social-ecological systems resilience (Shirk et al., 2012), including increasing the availability of long-term and spatially distributed datasets (Dickinson, Zuckerberg, & Bonter, 2010), strengthening motivations for stewardship (Couvet et al., 2008) and ecological literacy (Brossard et al., 2005), creating spaces for diverse leadership roles to grow and encouraging the formation of adaptive forms of governance (McGreavy et al., 2016).

5. Conclusion

In the face of widespread and rapid changes in coastal ecosystems and communities, the need to understand problem perceptions and contextualized visions of success remains an essential focus. From a communication standpoint, understanding perceptions about climate change, predation, water quality, and issues of human health and well-being creates a starting point for connecting across differences in the relative prioritization of these issues. Further, characterizing diverse and sometimes conflicting perspectives about problems helps establish a fine-grained and context-dependent understanding of what success means that provides a starting point for creating tailored approaches to adaptation within co-management.

We see an urgent need to find ways to wade into the complicated and sometimes messy work of working within co-management as a

space for bringing differences together in productive, creative, and equitable ways. As we describe, engaged communication research provides a model and flexible framework for doing so. Though the specific communication patterns that emerge in any locale will be shaped by myriad contextual details, focusing on strategic, relational, contextual/ecological, and equity-related factors provides a heuristic for tracing the multiple ways in which communication shapes adaptation (Scott, 1973; Druschke and McGreavy, 2016). Further, co-producing knowledge with research partners helps ensure that the research questions and resulting insights are relevant for the decision making needs (Cash et al., 2003). This approach also nurtures relationships and mutual understanding that can support the ongoing negotiation and uptake of knowledge (Clark et al., 2016; van Kerkhoff and Lebel, 2006), and this has proven to be essential in our ability to link our recommendations with demonstrated action. In our experience, an engaged approach can improve the ability of individuals and communities to anticipate changes, proactively respond, and begin to address power and equity issues for the systemic changes that are necessary to adapt and transform the fishery for the foreseeable future.

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Appendix A. Supplementary data

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